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Distributed Optical Fiber Devices Based on Liquid Crystal Infiltrated Photonic Crystal Fibers.

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Abstract: We describe a new class of hybrid photonic crystal fibers, which are liquid crystal infiltrated fibers. Using these fibers, we demonstrate 'distributed' tunable filter and switching functionalities operating by the photonic bandgap effect.

OCIS codes: (060.2310) Fiber Optics; (230.3990) Microstructure Devices; (230.3720) Liquid Crystal Devices

Introduction

Photonic Crystal Fibers (PCFs) have appeared as a new class of optical waveguides, which have attracted large scientific and commercial interest during the last years. PCFs are microstructured silica waveguides with a large number of air holes located in the cladding region of the fiber [1]. The size and location of these air holes openes up for a large degree of design freedom within optical waveguide design, and PCFs with properties tailored for fiber lasers, airguiding fibers, nonlinear fibers, hybrid fibers etc. have been demonstrated [2-5]. Further, the existence of air holes in the PCF gives access close to the fiber core and by introducing new materials into the air holes, a high interaction between light and hole material can be obtained, while maintaining the microstructure of the waveguide. In this paper, we describe what we call Liquid Crystal Photonic Bandgap Fibers, which are PCFs infiltrated with Liquid Crystals (LCs) in order to obtain increased fiber functionality. We describe a thermo-optic fiber switch with an extinction ratio of 80dB and tunable PBGs using thermo-optic tuning of various LC phases, and demonstrate the significance of the actual LC phase.

Liquid Crystal Infiltrated Photonic Crystal Fibers

Liquid crystals are organic materials consisting of geometrically anisotropic molecules, leading to long-range orientational [6] order and a number of *mesophases*, which are thermodynamic phases with physical properties intermediate between those of pure liquids and pure solids. Examples of mesophases are shown in Fig. 1, left. *Nematics* have only long-range orientational order, while *smectics A and C* in addition have long-range positional order in one dimension, resulting in a structure of thin (2-5 nm) layers; In case of *chiral* molecules, all phases become noncentrosymmetric, leading to a helical superstructure in chiral nematic (N*=cholesteric) and chiral smectic C (SmC*), but not in chiral smectic A (SmA*). Infiltrating the LCs into the holes of the PCF, gives rise to high-index inclusions, which refractive index properties are highly dependent on the molecular alignment of the LC. The periodic structure of the PCF combined with these inclusions gives rise to bandgaps in the PCF, which can be modulated by changing the optical properties of the LCs. The principle of this device is illustrated in Fig. 1, right, which illustrates a PCF, filled with a LC and coated with a thin conducting layer, which forms a resistive microheater. Below is shown polarized micrographs of SmA* and N liquid crystals inside a PCF hole and describes the alignment of the LC inside the hole. The waveguiding principle of this device is illustrated on Fig. 2, left, which shows mode indices of allowed states in a PCF with high-index inclusions. Bandgaps occur below the silica line (n=1.45) around a normalized wavelength of 0.3 and 0.55. In the bandgaps, a guided mode is supported, which is plotted as insets together with two cladding modes as illustration. From this figure it is clear that the mode in the bandgap around 0.55 is tightly confined, while the mode in the 0.3 bandgap is weakly confined since light also propagates in the high-index inclusions. Fig. 2, right, shows a micrograph of the end-facet of a PCF infiltrated with a cholesteric LC, which after infiltration only supports a finite number of guided modes. In this case, a green guided mode is supported in the visible range of the spectra.

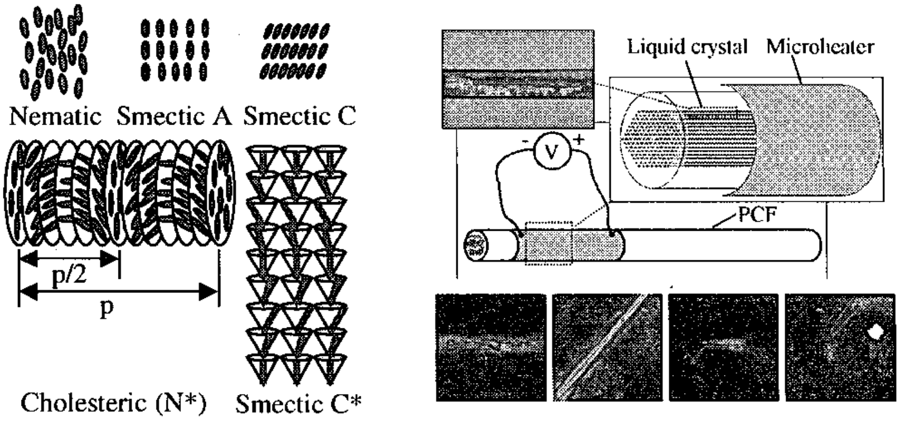

Fig. 1. Left: Examples of phases of thermotropic liquid crystals: Nematic, Smectic A and Smectic C phases (non-chiral molecules), appearing in that order upon cooling, if the same material possesses all of these phases. If the molecules are chiral, we instead have N* (=cholesteric), SmA* and SmC*. These phases all lack mirror planes. A helical superstructure due to the molecular chirality appears in the N* and SmC* phases (shown), but not in the SmA* phase (not shown).
Right, top: Device principle of Liquid Crystal Infiltrated Fibers. Infiltrated section is coated with a resistive microheater by which the temperature of the LC can be controlled. Right, bottom: Crossed polarizer micrographs of LC inside PCF void angled at different angles between fiber and polarizer : a) SmA* LC@0°, b) SmA* LC@45°, c) N LC@0°, d) N LC@45°.

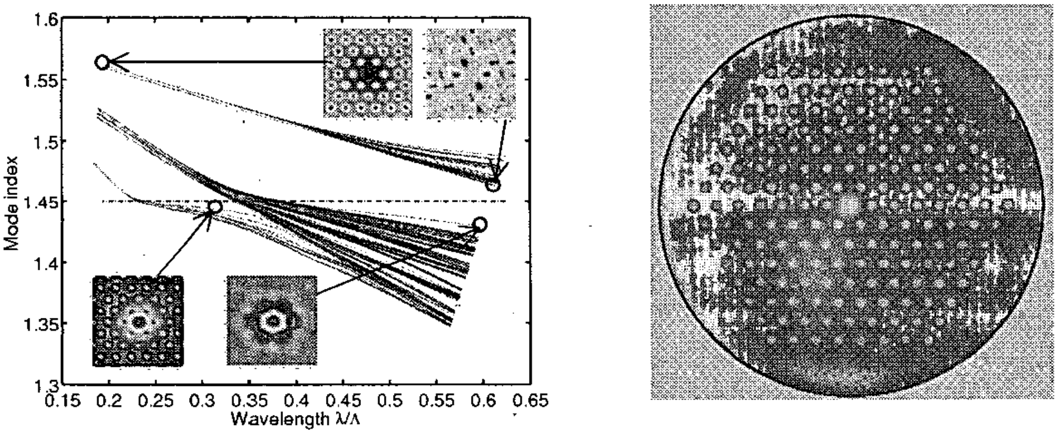

Fig. 2. Left: Mode indices of the first 300 modes in a triangular silica PCF with a high-index material (n=1.59) in the holes. Inset shows two cladding modes and two guided modes in the first and second bandgap. The guided mode in bandgap 2 is poorly confined since light is also guided in the inclusions. Right. Micrograph of the end facet of a PCF filled a cholesteric liquid crystal, which acts as high-index inclusions and a green guided mode is supported by the PBG effect.

Tunable Photonic Bandgap Fiber Devices

LC infiltrated PCFs have been tested using an all-silica triangular PCF with a pitch of 7μm and a holesize of 3.5μm. We have used 3 different LCs for our experiments: 1) a Cholesteric (MDA-00-1445, Merck), which is a nematic with a chiral dopant, 2) The nematic host (MDA-00-1444, Merck) used in the cholesteric and 3) a SmA* liquid crystal (TM216, BDH). Fig. 3, top left, shows the transmission spectrum of a LC PCF infiltrated with the cholesteric and with the nematic, which was used as host in the cholesteric. The major part of the molecules in these compositions is the same, namely the nematic host, but by adding a chiral dopant, the nematic(MDA-00-1444) changes into a cholesteric(MDA-00-1445) and thereby changes the alignment of the LC within the PCF hole. As shown on Fig. 3, this changes the transmission spectrum considerably. Fig. 3, Top right, shows micrographs of the guided modes at 4 temperatures of a PCF filled with the cholesteric LC.

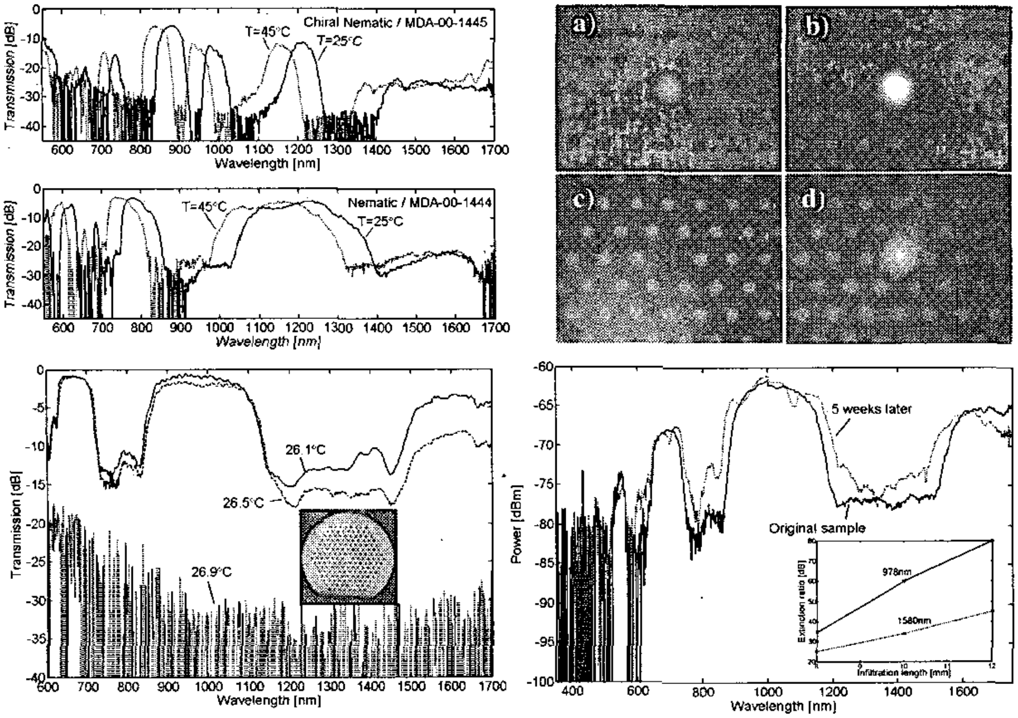

Fig. 3. Top, left: Transmission spectra of a PCF filled with a chiral nematic LC and with the corresponding nematic host LC. Spectrum is shown for LC temperatures of 25°C and 45°C. Top, right: Micrographs of the guided modes of a LC filled PCF. a) green@T=77°C b) yellow@T=89°C c) off state@T=91°C d) blue@T=94°C. Bottom, left: Transmission spectra recorded at 3 closely spaced temperatures of a PCF filled 10mm with a SmA* LC (TM216). Inset shows a micrograph of the end facet of the PCF. Bottom, right: Transmission spectrum of a sample (as in top left) compared to the spectrum 5 weeks later. Inset shows extinction ratio of 3 samples with 3 different infiltration lengths. Extinction ratio was measured at 978nm and 1580nm.

By utilizing the molecular reorientation at the SmA* to N* phase transition of TM216, which occurs at 26.2°C, it is possible to obtain a highly sensitive switching functionality in the fiber [7], which switches between a transmission (SmA* phase) and a scattering (N* phase) state within 0.4°C and has an extinction ratio of up to 80dB, while maintaining a low insertion loss of approx. 1dB. This is illustrated on Fig. 3, bottom, which shows transmission spectra of the filled fiber together with measured extinctions ratios as function of infiltration length. Also shown is the transmission spectrum for a sample tested after infiltration and tested again 5 weeks after infiltration. After 5 weeks, the spectrum shows similar shape as the first test, but more ripples and transmission dips occurs due to unknown reasons.

Conclusion

In this paper we have described a new type of hybrid Photonic Crystal Fibers, which have been infiltrated with Liquid Crystals in order to transform the transmission fiber into a fiber with build-in signal processing capabilities. We demonstrates thermo-optic tuning of Photonic Bandgaps, which arises when Photonic Crystal Fibers are filled with Liquid Crystals and thermo-optic switching of bandgaps with a very high extinction ratio of 80dB.

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